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A talk on American Science Tomorrow could with some justification be cast on a model of Christmas-to-come as related to Scrooge by Marley's ghost. A few years ago the rate of production of scientists and (not too surprisingly) the rate of production of scientific articles was doubling every ten years. Really new science was coming out at a tremendous rate, generating major new areas such as solid state physics, molecular biology, radioastronomy, and major breakthroughs such as the cracking of the genetic code, the discoveries of the transistor effect, of pulsars, and quasars, of techniques of stereospecific syntheses, of ultrasensitive methods of compound detection, identification, analysis, and structure determination, and of new fundamental particles in profusion. Of approximately 400,000 scientific papers published in 1967, about half were in English and the majority of these reflected work done in the United States. This science had dramatic consequences in technology and mode of life—in new materials for shelter and clothing (particularly polymers), the ubiquitousness of the high-speed computer, in communications and air transportation, in the arrival of atomic energy as the cornerstone of strategic military power and as a significant factor in civilian energy production, and in new drugs such as the contraceptive pill. This new technology had a major effect on the nation's economy—companies such as Xerox, Syntex, IBM, and Texas Instruments grew from small companies to giant corporations in under a generation, and the nation's balance of payments came to depend heavily on foreign sales by chemical, drug, and electronics industries whose innovations in science and technology were sufficiently excellent and frequent to permit effective competition even in the face of much higher per-man labor costs.

Nineteen hundred sixty-seven was a peak year for American science. In the face of continued inflation, federal funds for support of science grew negligibly in the next two years, and have been effectively reduced this year. Tight money has postponed industrial plant expansions, and accordingly industrial research staff growth has been sharply reduced. State legislatures also have been tightening appropriations—"it never rains but it pours"—so that there is at present a sufficient unemployment or underemployment problem to be of concern, and this is very likely to reduce the number of high school students who will choose to embark on scientific careers, and correspondingly the number of scientists appearing with bright new

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Ph.D.'s eight years from now. The effect of all of these happenings on American science is hard to put a number on, but I would judge personally that it has been set back to about 1962 in financial and manpower health and is in a downtrend which will require several years to reverse. This judgment is very close to one recently expressed by Dr. Alvin Weinberg,[1] Director of Oak Ridge National Laboratory. Presidential Science Adviser Dr. Lee DuBridge (from whom I suppose a less gloomy picture is expected ex officio) lets it go with "the nation's total scientific effort today is actually at a lower level than it was two or three years ago" (i.e., in 1966 or 1967).[2] Meanwhile, as DuBridge points out, the Soviet Union not only *presently* exceeds the United States in total scientific and engineering manpower, but is training both scientists and engineers at a greater rate than we are. Were I to extrapolate these trends and really play the role of Marley's ghost in forecasting science tomorrow, the rest of this talk could be devoted to probable contents of foreign scientific journals, especially Russian journals, ten years from now.

Science and technology provide options, sometimes rather complex options, and choices between options require thought and sometimes worry. To illustrate simply, one would not have to worry about whether or not to attend an aunt's funeral in Boston tomorrow if there were no way to get to Boston by tomorrow. The existence of world hunger would disturb our sleep less if we were really sure nothing could be done about it. Periodically it seems to me, the body politic becomes fed up with options, curses those who made them available, and simplistic ideas for solutions of the world's ills have a heyday. We will cure crime via the hangman, population growth by abstinence, minority problems with Auschwitz, and pollution by prayer, and anyone who wants to question the wisdom of these practices risks charges of effete snobbishness and pointy headed intellectualism. It seems to me that these periods have not usually been of long duration, and I am sufficiently optimistic to believe this one will not be either. In part, this opinion is based on my judgment that there are a number of really pressing national and/or world problems for which our present options are either not defined with sufficient precision or are inadequate.

Sufficiently high exposures to radiation or certain drugs can lead to extremely high cancer incidence. As exposures are reduced, the cancer incidence is reduced; suppose that at a given dose one in a hundred subjects develops cancer. Why that one develops cancer and not the other 99 is unknown—it may be pure chance or it may reflect a distribution of susceptibilities. Suppose the dose is reduced by a hundredfold; will the probability of cancer incidence be reduced a hundredfold? The answer to this question at low probability levels is subject to sharp present debate; some excellent biologists have maintained that there is an exposure threshold below which there is no probability of cancer (e.g., because cells will be so little damaged

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[1] A. M. Weinberg, "1969 State of the Laboratory Address," text published in *The Oak Ridger*, December 19, 1969.

[2] L. DuBridge, *American Scientist*, Winter, 1969, p. 546.

that they will heal themselves) while other excellent biologists believe that the probability remains proportional to the dose as the dose becomes arbitrarily low. Questions of policy with respect to drug tolerance, radiological discharges, and pesticide residues depend critically on the answer to this question.

Electric power demand in the United States has been approximately doubling every ten years. The projected demand can be handled without bothersome environmental problems through perhaps the first decade or two of the next century *if* the fast breeder reactor (currently developing well but by no means completely developed) is available for commercial power in 1980 as planned. Beyond 2010 continued growth in power demand at this rate is likely to cause serious concern about the magnitude of radiochemical waste and thermal pollution if power is to continue to be furnished by fission reactors. The fusion reactor (concept feasibility not yet demonstrated but 1978 has been a steady goal for this demonstration for several years) would not only solve this problem but would very likely lead to electricity "too cheap to meter."

Mother earth is a pretty good recycling machine for some of society's refuse, at least in moderation, and of course has been recycling natural organic wastes for millenia. Policies for dumping man-made wastes on our environment should reflect the environment's ability to handle them, and this ability varies markedly with the waste (the transition to biodegradable detergents reflects such considerations). In some rather important cases we do not know what the environment does with the waste. Carbon monoxide is the largest volume toxic gaseous waste. It appears to have about a three-year half-life in the atmosphere. Presumably it is oxidized to carbon dioxide but this is not known for certain nor is the mechanism by which such oxidation occurs (if it does). We do not know what the environment does with many pesticides and with many inorganic wastes, and as a result do not know how to make sensible policies for regulating them.

A final pair of illustrations pertains to the need for inexpensive options. The General Electric Company made a fuel cell automobile, with size, comfort, and performance characteristics very like those of a new Ford automobile, but with negligible exhaust other than water and carbon dioxide. The platinum in the fuel cell cost $3,000 so there was no way of making this automobile for less than twice the cost of a regular Ford, and it was therefore commercially worthless (in the absence of laws making regular Fords illegal). Had G.E. been able to think of a material which performed in a fuel cell like platinum but which cost like nickel, they would have gone commercial. They couldn't, and after several years and many million dollars spent trying, they gave up. Silting of agricultural soil is probably the major water pollution problem in Iowa and the topsoil loss is of course also a loss to the farmer. There is a class of polymeric compounds which are effective soil conditioners and tend to reduce silting markedly. Unfortunately an effective application costs about $2,000 per acre.

Pure science of tomorrow will consist in part of today's unsolved problems plus new problems as yet unimagined. Some of today's problems look rather close to solutions, some rather far away. In some cases the solutions would generate obvious technological options, in others applications of solutions have not yet been imagined.

Although high-energy physicists have managed to study nuclei with accelerators of energies undreamed of a generation ago, have discovered large numbers of fundamental particles previously unimagined, and have devised remarkably clever and complex schemes correlating their behavior, we do not understand in a basic way what holds the nucleus together—we do not know what the nuclear analog of Newton's law of gravity or Coulomb's law for electric charge is. Quasars appear to generate energy at a rate too great to be accounted for by any known process. This phenomenon is a current frontier in experimental and theoretical astrophysics. When some materials, called superconductors, are cooled below a critical temperature their resistance falls sharply to zero or nearly so. Some of these materials can be used to prepare electromagnets having extremely great fields with almost negligible power consumption. So far no one has found a material superconducting above about 20° above absolute zero (i.e., about the boiling point of hydrogen) and even so considerable use has been made of superconducting magnets. We do not know in any really basic way why a material superconducts, where to look for new superconductors, and especially what to do to make a material which will be superconducting at substantially higher temperatures. We also do not understand magnetism very well, at least in the sense of being able to predict in advance that a given element, alloy, or compound should make an excellent magnet.

The high-speed digital computer has had a tremendous effect on the kind of research done by chemists and physicists particularly. Prior to its advent, many problems were simply not undertaken because the calculations involved would have taken a man's entire professional life to do. Why molecules stayed together, for example, was solved in principle with the advent of quantum mechanics, but the calculations required could only be done for the simplest molecule, i.e., hydrogen, in a practical way. As a result, theoretical questions of real interest to chemists, for example why is the behavior of a carbon-hydron bond in zeroth approximation nearly independent of other groups attached to the carbon, and in first approximation what will the variations in behavior be like, went unanswered. Theoretical chemists are solving problems like this now. The change in calculation speed has radically changed some experimental programs. Molecular structures, for example, have long been determined by X-ray diffraction, i.e., by analyzing the interference patterns resulting from shining a beam of X-rays on a crystal. This analysis requires extensive calculation if the molecule is complex, and until the computer came along such molecules simply were not done. Within very recent years the complete structures of myoglobin, hemoglobin, and six enzymes have been established.[3] There are now commercially available fully automated X-ray diffractometers; the Ames Laboratory has one and a second will be installed this spring. Within the next decade, techniques will develop to the point where a protein structure can be done for a Ph.D. dissertation and we will be well on our way to establishing in detail how enzymes perform their catalytic functions. Within the last year, one of these enzymes, ribonuclease-S, has been totally synthesized; once the structure is established the matter of synthesizing an enzyme appears to be quite possible in general. Furthermore, once the structure of a given enzyme is related to its function, the possibility of making other compounds, probably enzyme-like, which will perform this same function arises and it is quite certain that serious efforts to do just this will be made in the next decade.

There are two other biological problems that are very likely to be at least partially solved in the very near future. We believe that every cell even in a complex organism contains the genetic information for the complete organism. This has been proven for frogs by cloning experiments—the complete frog has been generated from DNA contained in frog eye tissue. (It should be noted that this experiment has some Brave New World implications—in principle it means we could replicate Einsteins—or Hitlers—at will.) The question of cell differentiation is one of the most pressing problems in modern biology—if the frog's eye tissue has the complete genetic information for the whole frog, how is, e.g., the liver-making information suppressed in the eye and the eye-making information suppressed in the liver? Another problem on which some very suggestive experiments have been done is memory. There must be a kind of mechanism such that it is easier to make an association a second time than a first and yet easier to make it a third time; this mechanism must somehow be stored in the chemistry of the brain but how is unknown.

"Science Tomorrow" would obviously be handled very differently by different speakers, and I freely admit to flavoring my presentation with my own biases and experiences. I think the majority of active scientists would agree with the following summary:

(1) American scientific and technological health is less than it was a few years ago and is presently decreasing. (The arguments have to do with whose fault this is. I associate it with a temporary anti-intellectualism in the body politic rather than with a particular administration. Sources of this anti-intellectualism are also subject to debate.)

(2) There are important technological options which need to be provided and/or clarified if our society is to remain healthy. I have mentioned some, other scientists might have chosen others but it is quite easy to show that most problems that "bug" the lay public are not going to be solved without further science and tech-

[3] See, for example, D. C. Phillips, "The Three-Dimensional Structure of an Enzyme Molecule," *Scientific American*, November, 1966, p. 78.

nology. Hence, society cannot and will not tolerate a continued decrease in scientific strength, and the decrease must therefore be a temporary one.

(3) Science remains an "Endless Frontier." The problems we can recognize now will generate exciting answers in many fields within the next generation, but we can be sure from past experience that these answers will generate new problems equally exciting.

Parks Suspend Entrance Fees Pending Congressional Action

The Department of the Interior's National Park Service has suspended entrance fees to park areas normally entered by automobile pending Congressional action on restoring the Golden Eagle Passport, an annual fee system which expired last March 31.

National Park Service officials said the collection of daily entrance fees appeared to be working a hardship in a number of areas, and had aroused numerous public complaints.

The Service announced that all "user fees" for services within park areas will continue to be collected.

These include such nominal charges as 10 cents for the elevator ride to the top of the Washington Monument, and for overnight camping, cave trips, and bathhouses at public beaches.

In accordance with the Department of the Interior's general policy, appropriate charges will be made for camping, except backcountry camping. Overnight camping fees in the National Park System range from $1 for primitive campgrounds to $3 where more sophisticated facilities are available.

Under the Land and Water Conservation Act of 1965, the Golden Eagle Passport was a $7 annual charge which allowed the purchaser unlimited in-and-out privileges for all those in his private motor vehicle at national parks, national forest recreation areas, some wildlife refuges, and other public lands. When the Golden Eagle Passport legislation expired March 31, National Park System areas began collecting admission charges on a daily basis, in anticipation of early Congressional determination of the fee question. Those are the admission fees now being suspended.

In September, 1969, the Senate passed legislation to continue the passport indefinitely, but at an annual fee of $10. As amended by the House Interior Committee, the legislation pending in the House of Representatives provides for a $10 annual fee until December 31, 1971—and asks for a comprehensive report on the fee system by February 1, 1971. The pending bill is S. 2315, to extend the fee provisions of the Land and Water Conservation Fund Act.

The suspension of entrance fees applies to all National Park System areas except at Jamestown Island, Va., operated under a fee-sharing cooperative agreement with the Association for Preservation of Virginia Antiquities.